

# The Collaborative Virtual Affinity Group Model: Principles and Design

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**Abstract** The problem addressed in this paper is the challenge arising in enabling collaborative learning in the context distance education models. While research has made quantum leaps in the development of both effective collaborative pedagogical models as well as online learning environments, the research at the intersection of these two areas has been scarce. This paper presents the design for a new collaborative virtual model, named *Collaborative Virtual Affinity Group model (CVAG)*, which is an extension of the successful Affinity Group Research (ARG) model. The new model provides an integration of the principles underlying ARG with the traditional principles of virtual learning environments. The CVAG model is explored in the context of introductory Computer Science courses—where students are focused on learning the basic principles of computer programming.

**Keywords** Affinity Groups · Collaborative Virtual Environments · Introductory Programming

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## 1 Introduction

### 1.1 Motivation

The role of collaborative learning [5, 18, 19] has been widely explored in the pedagogical literature and practices. The theoretical foundations for collaborative models of learning, especially in scientific areas like mathematics and computer science, can be found in the seminal work on *constructivism* [9, 11], where the learning process is viewed as active participation of the student, engaged in a process of recursive construction of knowledge. The student builds new cognitive structure from the combination of his/her existing knowledge, the experience imparted by the instructor, and the interaction with peers. In particular, these considerations span from social constructivism in teaching and learning [37], bringing into account the role played by the immersion of the student in a community of learning; the physical and social experience of interacting with other students provides a valid scaffold to the learning experience.

The role of collaboration in the learning experience has been shown not only to provide an effective pedagogical instrument, but also to facilitate the engagement of students from traditionally underrepresented backgrounds [6, 35]. The role of collaboration is well aligned, for example, with traditional values found in Hispanic communities. Hispanic families are characterized as valuing family needs over individual needs [31], strong loyalty and reciprocity among family members, and high regard for behaving respectfully and in ways that promote harmony [17, 23]. Hispanic students share a collectivistic culture, which values the role of shared responsibilities, and where accountability is towards the group [36].

Computational tools and methods have gained a central role in supporting collaborative learning; innovative computational instruments have been proposed to promote interaction between students, provide challenges, and facilitate data collection and analysis for the benefit of instructors [3, 7, 25, 34]. Indeed, an entire research field has developed focused on computer-supported collaborative learning (e.g., [10, 26, 32, 33]).

The role of collaborative learning has gained momentum in a variety of scientific disciplines. In the area of Computer Science, collaborative learning models are at the foundation of several successful pedagogical methodologies (e.g., peer-led team learning [2], pair-programming [38]). The *Affinity Research Group (ARG)* model [14] is a formal model developed, in the context of Computer Science education, to promote structured research groups composed of undergraduate students, where students with diverse backgrounds and levels of preparation are made active participants in both the research and learning experience. ARG has been shown to be a very effective group model in promoting learning, participation, engagement and inclusion [15, 20].

## 1.2 Summary of Contributions

The success of the ARG model has been validated in a variety of settings, within different research areas and with students from different backgrounds and levels. Nevertheless, the ARG model has been applied exclusively in situations that are **spatially** and **temporally** bounded. The *spatial* bounds lead to applications of ARG that are entirely face-to-face—i.e., a team of students working on a project in class. The *temporal* bounds imply that the operations of an ARG team are synchronous, and often limited to a specific time period (e.g., a lab session). Both bounds represent obstacles to a broader use of ARG, to support research and learning teams that are distributed. Such transition, in particular, is critical to enable the use of ARG in the context of distance education and online courses.

In this paper, we propose the design of the *Collaborative Virtual Affinity Group (CVAG)* model. CVAG represents an extension of ARG that relies on the use of *Collaborative Virtual Environments* to promote the formation and operation of distributed affinity groups. In order to guarantee feasibility, we explore the design and development of CVAG in the focused context of affinity groups of students learning introductory computer programming—or engaged in research projects associated with basic programming. Hence, CVAG can be defined as a collaborative virtual model that supports distributed affinity groups of students to learn computer programming in a collaborative manner.

## 2 Brief Literature Review

### 2.1 The Affinity Research Group (ARG) Model

The Affinity Research Group model (ARG) is a model to structure and operate undergraduate research teams [20]. Specifically, it is a comprehensive model for creating and maintaining dynamic, productive, and inclusive research groups. ARG creates a cooperative environment designed expressly to allow each member (e.g., faculty mentors, undergraduate students, and graduate students) to flourish [21]. In ARG, research goals are shared among group members, in addition to academic and professional development goals. This affinity is the basis for promoting cooperation in achieving goals. The contributions of each group member are essential to the group’s success—which is defined as reaching a set of goals which have been agreed upon by the entire group.

ARG was developed by researchers at the University of Texas at El Paso, under funding from the National Science Foundation [14]. The motivation behind the name ARG can be found in the fact that research group members that use the ARG model develop an *affinity* for the particular research topic [14]. The creators of ARG found that undergraduate research is very important for helping students to identify the skills and knowledge they need to successfully participate in research projects, and appreciate the rewards of graduate

study. ARG has been formally studied and shown to increase the ability to do research, improve students' self-efficacy, and enhance skills in presenting and defending ideas [21]. There is empirical and experimental evidence showing that the use of ARG leads to improved retention and graduation of students in Computer Science, Electrical and Computer Engineering, especially students with deficiencies and low levels of confidence [20].

The philosophy behind the ARG model is to maximize each student's ability to reach his/her potential. It is built on the principle of consciously developing and training researchers in a cooperative environment, offering to the team members specific roles and rules of operations. The dynamic assignment of roles to team members is aimed not only to enable the team's progress towards its goals, but also as an intentional development of the skills and sense of responsibility of each team's member. Throughout the lifetime of the research group, the members alternate in the different roles, including the roles of leadership. The dynamic reassignment of roles allows each team member to develop different skills and ensures that each member has the opportunity to contribute to the team goals. It also ensures that each member is accountable for her/his contributions to the team activities. In particular, in the context of educational applications of ARG, the leadership roles are shared between students and faculty members. The ARG model began as a mechanism to enhance retention of students from traditionally underrepresented groups, such as female students, in computing disciplines. The model has evolved since, making it suitable for a variety of undergraduate groups [14].

The ARG model strives to structure group interactions in a way that fosters positive interdependence and promotive interaction, generally yielding the following outcomes:

- Establishment and maintenance of cooperative groups and subgroups;
- Achievement of research deliverables; and
- Self-development of group members, who acquire teaming and research skills and progress in cognitive and emotional development.

Using structured tasks and activities, ARG encourages students to:

- Develop domain expertise,
- Understand and appreciate the research process and its practice, and
- Acquire team, communication, problem-solving and high-level thinking skills that will make them effective leaders and successful in research, academia, and industry.

Let us contrast ARG with more traditional models to structure and operate research groups. The traditional models tend to rely on hierarchical/pyramid structures, where the layers represent a decreasing order of expertise and authority. While ARG does incorporate aspects of the traditional models (e.g., peer-to-peer relationships between team members), it also differs deeply in several important aspects, as summarized in Table 1.

Furthermore, ARG can be applied to virtually any type of groups, allowing for a broad range of diversity between the group members (e.g., capabilities, interests, skills, education, culture, backgrounds, and experiences). This

Category	Traditional Model	ARG
<i>Leadership</i>	The leadership position is reserved to the faculty mentor and s/he is only the person who provides direction to the other group members	Each student acquires the skills to be a leader and expert in some aspect of the research that the group is doing as a whole
<i>Tasks</i>	Members are often concerned about the progress of their individual project	Members are concerned about the progress of the team's project
<i>Participation</i>	Only the best and brightest are recruited, and undergraduate students are rarely included	Heterogeneous membership is encouraged, and undergraduate students are recruited
<i>Skills</i>	"Necessary" research and technical skills are taught	Research, technical, team and professional skills are emphasized and explicitly taught
<i>Development</i>	Professional skills are assumed	Professional skills are developed through structured activities
<i>Environment</i>	Environment is controlled by the research leader and may be competitive	Cooperative environment is a key part of the model and is encouraged and developed
<i>Improvement</i>	Process improvement is not practiced or is as hoc	Process improvement is part of the model

Table 1: ARG vs. Traditional Group Models

is thanks to ARG's infrastructure, which provides students with active mentoring and continuous training in research.

## 2.2 Collaborative Virtual Environments (CVE)

There is an extensive literature exploring the nature and role of *Collaborative Virtual Environments (CVEs)*—viewed as multi user, distributed worlds [22]. The authors of [16] define CVEs as “computer based systems which actively support human collaboration and communication within a computer based context”. The author of [29] define CVEs as “computer-enabled, distributed virtual spaces or places, in which people can meet and interact with others,

with agents and with virtual objects”. The other definition of CVEs by [22] is “connected computer systems aimed at the fulfilling of a certain collaborative task within a generated 3-D virtual environment”.

A collaborative virtual environment provides a framework to enable collaborations among a number of users, working on a common task in a spatially distributed scenario. According to [16], there are a number of basic properties that underlie the design of most collaborative virtual environments:

- CVEs are multi-user computer-based systems which support geographically dispersed users;
- CVEs provide the user the ability to collaborate and communicate in a number of different ways;
- CVEs are virtual environments—i.e., they are based on a virtual space or world, where all activities are performed;
- Each user is explicitly represented within the virtual environment and visible to other users by means of embodiment;
- Each user is independent from the others and has the ability to make any movement within the virtual environment independently.

CVEs have found extensive use in the domain of online education, and a number of educational CVEs have been developed and discussed in the literature. Liebrecht [22] studies six different CVEs to answer the following question: what is the potential of CVEs as learning tools? Table 2 contains a comparison between these six environments with their features and other characteristics. The study concluded that CVEs provide a number of advantages in an educational setting:

- They support the social awareness of university students;
- They increase communication and discussion possibility on a wide scale;
- They support constructivist learning on different subjects aimed at different age groups;
- They increase information available to users;
- They enable collaborations that culminate in sharing and creation of new knowledge;
- They provide virtual experiences that facilitate the learning of challenging concepts using different learning strategies.

### 3 The Theory Behind the Model

In the last decade, a large number of virtual and interactive technologies have been proposed to enable the learning of introductory programming; these technologies are designed to support a diversity of learning styles and backgrounds. At the same time, we have witnessed the extensive development of learning management systems that make it possible to support “learning at a distance,” meeting the needs of online and distance education.

In this paper, we present the design of new collaborative learning model, referred to as the *Collaborative Virtual Affinity Group (CVAG)* model. CVAG

Name	Development reason	Features	Audience	How to access	Hardware requirements
CVE-VM	It is a part of the virtual museum projects	Text chat	Children and teen-age students	Internet using a computer and browser	No
DeskTOP	Supports and promotes collaborative learning in universities	Slider tool, audio and video, news-group tool	University students	Internet	No
DigitalEE and DigitalEE II	Uses a CVE in environmental education	3D virtual representation; text chat, voice communication, avatar	Learners, virtual tourists as well as experts on the environment	Desktop computer with Internet and mobile computer equipped with GPS	Mobile computer equipped with GPS, digital camera
NICE	Investigate how effective a CVE can be when used for learning and evaluation	Gestures (avatars), spoken word, text chat	Children between 6 and 10 years old.	Desktop computer connected to the Internet	Digital camera, Special glasses, sensors etc.
Round Earth	Builds according to NICE. Supporting the education on a difficult learning problem.	As NICE	As NICE	As NICE	As NICE
Viras	How different factors of CVE impact on the social awareness. How students experience CVEs meant for increasing social awareness.	Avatars using chat, sending messages and making gestures	Students	Desktop computer connected to the Internet.	No

Table 2: A comparison between six different environments

is designed to be used to teach students introductory programming using a virtual environment. The core ideas for the model are analogous to those of the ARG model, but extended to enable their use in a distributed setting using a collaborative virtual environment. In this section, we present first a general overview of the model, followed by a discussion of the main components of CVAG, as they derive from ARG, and how the components of ARG have been adapted to enable their use in a distributed virtual environment. On the other hand, CVAG includes a number of collaborative environments components and properties. The final subsection discusses the CVAG as a collaborative virtual environment and how the CVE components mapped to be the essential components of CVAG.

### 3.1 Overview

Following the considerations made above, we can intuitively define CVAG as *a collaborative virtual model that support affinity groups of students to learn computer programming in a collaborative manner*. The new model supports

the process of collaborative learning, by inheriting from ARG the features and components that support the collaborative learning process, improve learning experiences, and enhance programming skills. These features are combined with the benefits of collaborative virtual environments, such as the ability for the group to work together and achieve common goals, regardless of spatial location.

CVAG shares ARG's emphasis on the development of structured working groups as a mechanism to create learning opportunities for the students, where students learn to use and integrate their knowledge and skills as required for their research and work. The design of the CVAG model illustrates the foundations of building an educational process to learn programming in a social context; CVAG provides a framework for each member of a team to learn, participate and share experiences and skills with members of the group. Each member is expected to interact and participate along the entire life-cycle of the learning experience—as ARG emphasizes accountability and awareness that each team member's contributions are essential for the success of the whole team; any failure affects negatively not only the individual student, but the whole group. In order to achieve such behavior in a truly distributed setting, where students may be located at different sites (e.g., at home, at different institutions), CVAG reinforces the creation of customized collaborative environments to learn programming and to support collaboration, communication and social interaction, involving both students and instructors, and relying on shared virtual workspaces.

### 3.2 Model Components: Elements of Collaboration

CVAG extends ARG's components and merges them with the five elements of distributed collaboration: positive interdependence, face-to-face promotive interaction, individual and group accountability, professional skills and group processing [12, 14]. The five elements of collaboration are used to organize the work of the group, determine the methods that are used to ensure achievement of the group's goals, and decide what are the required features to facilitate the work of the group members. The success of the group depends on the success of each member in the group, therefore each member has a responsibility to complete their assigned task to support the success of the whole group. In CVAG, the five elements are enhanced to support the group work within a virtual environment. Let us elaborate on each of these collaboration principles to illustrate how they are captured in CVAG.

#### 3.2.1 Positive Interdependence

Each member in the group understands that his/her contributions are essential for the success of the whole group and s/he has to finish his/her part successfully. In CVAG, following the ARG model, we rely on the use of *roles* to scope



the duties of each individual team member; roles are assigned at the beginning and dynamically revised throughout the execution of a project (e.g., a classroom project). Each role is supported by a number of features, which support the role functionalities (e.g., a note-taker receives a special white-board to write notes about the work). CVAG gathers information of the work's progress and shows the amount of contribution made by each member. Such statistics assist the supervisor (e.g., an instructor, a team leader) to evaluate each member's contributions, to assess the overall progress towards the goal (e.g., the completion of the homework), and make decisions on how to organize the work process (e.g., introduce new lecture modules to fill recognized learning gaps). CVAG ensure positive interdependence by:

1. Providing a shared workspace that all members can access, with guarantees of consistency, to collaborate on a shared group project (in our case, the development of programming project in an introductory programming course);
2. Each programming effort is divided into tasks, and each member has to finish a specific task to lead to the completion of the effort.

### *3.2.2 Face-to-Face Promotive Interaction*

CVAG provides a learning environment for the group, where members are enabled to share knowledge, help and encourage each other's effort to learn. In CVAG, a number of communication channels are provided to the team members—i.e., text chat, audio, and video—and three types of meetings are supported to allow students' interactions—orientation, small group meetings and large group meetings. We will describe these phases in detail in a following section of this document. Intuitively, in a small group meeting, students have a conversation all the time while they work, share knowledge and help each other. In large group meeting, they share what they achieved and discuss the whole group progress and encourage each other to finish, and celebrate with members that finish their jobs successfully.

### *3.2.3 Individual and Group Accountability*

Achieving a team's common goal requires contributions from each member in the group. CVAG assesses the performance of each individual, by collecting information about each member's contributions for each type of transaction. The statistics can be reviewed by selected members in the group and by the supervisor (e.g., the teacher).

### *3.2.4 Professional Skills*

In CVAG, students learn problem solving, while practicing how to operate effectively within a team. CVAG's assignment of roles, with associated features and restrictions, is designed to scaffold the development of professional

skills, such as time management, communication, note taking, summarization, accountability, and critique.

### *3.2.5 Group Processing*

Group members should decide how the group goals can be achieved and what is the best method to work together. At the beginning, a team leader or supervisor (e.g., a teacher) assigns roles to each member in the group; nevertheless, these roles are dynamic. Therefore, group members and the supervisor can change roles, as needed to achieve the project goals and meet the expected learning objectives—e.g., ensure that each student actively expresses ideas and opinions. This type of change can happen during the small or large group meetings, and after discussing the results and work progress. Moreover, a meeting can be held to discuss and determine what are the required changes that can help to improve the progress.

## 3.3 Model Components: Principal ARG Components

The other components of CVAG are the result of mapping the essential elements of ARG into CVAG: core purpose, students connectedness and management scheme. These three main components are enhanced and modified to be suitable to be used in CVAG.

### *3.3.1 Core Purpose*

In ARG, one of the main initial steps is to identify the core purpose and core values of the group. This step is mapped directly to CVAG. Core purpose determines the reason for the group's existence. During the orientation phase, the supervisor defines the core purpose for the group; the core purpose provides to the team a clear vision to drive the group's planning, in addition to offering metrics to assess progress. The group will use the core purpose as a guidance and inspiration to work together to achieve the common goals. Moreover, the core purpose is a good start for the group to define the core values. CVAG embraces the same three core values as ARG: student success, cooperation, and excellence [14].

### *3.3.2 Student Connectedness*

Studying programming while working with a group is not a familiar technique for most new students. Therefore, the supervisor has to provide a clear description of each individual task and the connection of how the different tasks contribute to the overall project goals. The description should be available for all group members and everyone can access it any time. CVAG provides a space for the supervisor to publish the clear description. In the orientation, the supervisor explores students' perspectives and concerns, and establishes

the initial tasks based on the students' experience and skills. Students are given the opportunity to discuss the requirements within the virtual environment.

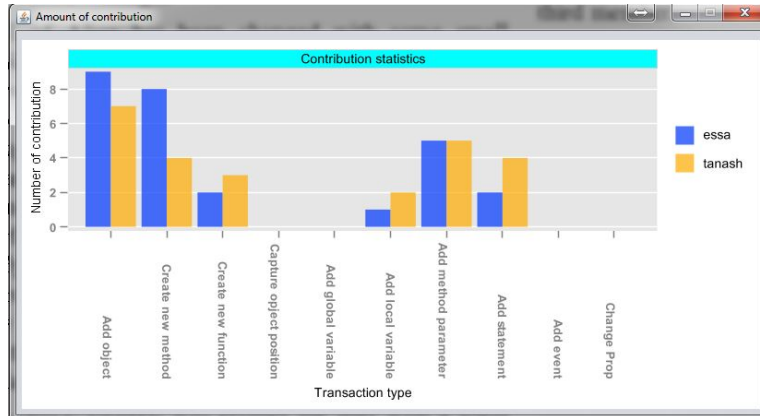


Fig. 1: Example of the type of statistics that CVAG can provide to the supervisor and students—the example shows the contributions of two students

### 3.3.3 Management Scheme

The concepts of *team* and *team management* are critical components for the success of the CVAG model. Learning to program and applying programming skills to specific problems are challenging tasks. They require students to learn and practice a number of skills in order to produce a good quality software artifact. In addition, learning to program within a team requires additional skills, in terms of communication, accountability and interaction patterns. The supervisor *defines the dependencies and time-line* for each part in the project. CVAG assists the supervisor in determining the work steps, dividing the programming tasks into parts, distributed as stages along a time-line. In particular, the CVAG supports the work for the group to be mentored:

1. The supervisor determines the stages and the time-line for each stage.
2. Roles are assigned to students at the beginning (e.g., the roles can assigned randomly, by vote, based on students' preferences, etc.). Roles are dynamic and they can be changed at any time.
3. The system collects information about the progress in the project, by saving data about each transaction performed (see Figure 1) (e.g., type, time, who made it, etc.).
4. The collected data can be used by the supervisor, students, and the system. The supervisor can review the progress and evaluate the students' contributions, modify roles and determine learning progression and needed

learning interventions. Students can use the information to encourage each other, discuss and resolve common challenges, and identify alternative roles that might be considered.

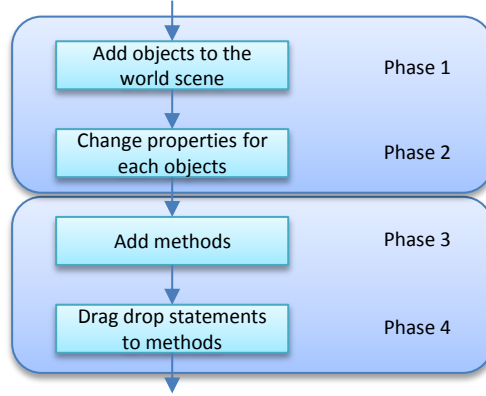


Fig. 2: An example for a number of phases to build a world in Alice programming language

The other important thing that the supervisor has to clearly define are the *expected deliverables*. Each task is divided into a number of subtasks, typically leading to a hierarchical decomposition of the overall task. Each level in the hierarchy is assigned to a specific working phase. Therefore, students cannot proceed to next phase (subtask(s)) until they have completed the current phase or some relevant part of it. The example in figure 2 shows that in phase 1, students need to add objects to the world scene, then change the properties for each object in phase 2. These two phases can be overlapped, where students can justify the properties for an added object before it is complete adding other objects (the same thing for phase 3 and 4). Whatever technique is used (finish adding objects first then change properties or changing properties while adding objects), students can deliver a world scene that contains the required objects after completing the first phase, and after phase 2, they can deliver how the world will be after they finish justifying properties for all objects, etc.

In CVAG, all the students will operate on the same workspace (i.e., viewing the same version of the program being developed); this allows the supervisor to maintain a view of the overall work been performed in each group. The CVAG provides also alerts to the group when the time has come to make a submission. The group leader can submit the deliverables when the team has completed the work or when a deadline has been reached. At the time of submission, the CVAG will clone a version of the workspace for the supervisor and alert him/her that the group has performed a submission. .

*Activities* and *meetings* are two other important components of CVAG. CVAG requires the activities and meetings to be structured in such a way to make them suitable to be used in a virtual environment. In the next two sections, we will discuss activities and meetings in detail.

### 3.4 Group Activities and Members' Roles

CVAG is an environment to teach students the foundations of computer programming; as such, it is important for the model to capture the fundamental activities associated to the process of software development, especially in the perspective of exposing inexperienced students to such processes. Thus, the expectation of CVAG is not only to serve as an instrument to support collaborative learning of introductory programming, but also as a tool to introduce students to the formal and informal aspects of team-based software development.

CVAG supports four types of activities that students can practice: analysis, design, coding, and testing. Let us review these four tasks and the relation between the activities and the available *roles* provided by CVAG.

#### 3.4.1 Analysis

**Analysis** focuses on the understanding of the initial activities required of the students. After students receive their tasks, each group starts by analyzing the task requirements. The *analyzer* is a role that is initially assigned to all of the students; the only distinction is the presence of a *lead analyzer*, which is assigned to one member, who will serve as the leader for the group.

*Example 1* In *AliCe-ViLlagE* [1], a collaborative virtual environment for pair programming in Alice [8], at the end of the analysis activity, it is expected that the students will be able to provide a comprehensive design of how to create a desired world scene, along with a breakdown of the design in terms of a list of required Alice objects, a list of properties with their values for each object, and a list of methods. A short description is also expected to be added for each item in the list, to explain how each element contributes to the overall design. Students can communicate using any communication media available, to discuss the task, ask questions to each other, and make a decision about the overall design and each list.

CVAG, should provide features to support the activities of all students in this phase. The leader student has the ability to set up the lists and other work areas, where the other students in the team can interact and exchange ideas. When the leader adds any item to a list, it is shared directly with everyone in the group. CVAG's features for the analyzers include support for team discussion, the ability to take personal and shared notes and collaborate in the development of the lists of objects, methods and attributes that are established by the lead analyzer.

### 3.4.2 Design

The second activity is the **design** activity. To make our discussion more concrete, let us focus the role of CVAG to the problem of designing applications for introductory programming environments, where students construct stories, scenarios, and virtual worlds. Students in this phase work to create simple program scenarios. Therefore, at the end of these activities, the students are expected to submit a script that contains the use cases. The script usually contains answers for a number of questions, such as:

- How users will use the application?
- What are the different functionalities provided by the program?
- What are the series of events in the story?

*Example 2* Let us assume that students are asked to tell a story using *AliCe-ViLlagE*. The students will have to develop a script for the story. All of the students in the group work together to create the script—thus, they all act as *designers*. Everyone in the group will write his/her notes about the design and contribute to the discussion leading to the script design. The team leader (i.e., the *lead designer*) will summarize the final decisions concerning the script. The features provided by CVAG allow the leader to incrementally write the script and share automatically with the whole group. The other members in the group can view the script but they cannot edit it. They can comment and participate in the discussion (using text, audio and/or video).

In both the analysis and design activities, the leader role can be reassigned at any time according to the supervisor and the group's decisions.

### 3.4.3 Coding and Testing

**Coding** and **testing** are the two most time consuming activities for students learning to program. The work on these activities can be done in one phase or can be divided into two or more sub-phases according to the supervisor's requirements and how s/he defines the deliverables.

*Example 3* The supervisor asks students to create an interactive story. The supervisor can divide the work in two phases: **(1)** the story without user's interactions and **(2)** The story after adding users' interactions. The main roles in these activities are *author (driver)* and *navigator*. While the driver is in charge of writing the actual code, the navigator serves as reviewer, debugger and advisor. In CVAG, the supervisor is allowed to establish an arbitrary number of drivers and navigators in the team. The author is the member that works on creating the application by adding the required objects, changing properties, adding methods, etc.; the navigator follows the author. Testing can be performed at any time. When any member has any notes about a test, s/he can transfer the information directly to the group using any communication media (text chatting, audio, or video).

Observe that the coding and testing activities can be alternated in an arbitrary manner, as decided by the team members.

### 3.5 Analyzing Member Roles

Leader, analyzer, designer, author and navigator are the roles that we mentioned previously in relation to specific activities. Table 3 contains a list of roles that have been described in ARG, along with the identification of which roles are also present in CVAG. A brief description of each role is provided in Table 4. In CVAG, students collaborate synchronously to complete the required task. This enables team members to dynamically switch between different roles. For example, the concurrent development of code suggests the presence of multiple authors; similarly, an author can hold, at the same time, the role of explainer. Similarly, the group leader can act as an author at the same time as s/he is the leader for the group, therefore, CVAG allows him/her to take notes, send messages, etc. as a leader, and allows him/her to add, modify, edit the code, etc. as an author. CVAG allows students to choose what roles they act at any point in time—or such roles can be predefined and pre-assigned by the supervisor (e.g., the teacher).

CVAG's ability to allow dynamic modification/reassignment of roles creates opportunities for very flexible programming group models. There is a significant value in allowing this type of extension:

1. It allows the team members to alternate in the roles that are provided (e.g., upon switching phase in the project)—this has a strong pedagogical value, as it allows students to experience different duties and activities; this also contributes to the development of a greater understanding of the overall team work and greater level of accountability. It is expected, for example, for a teacher to force the rotation of roles to ensure that each team member effectively contributes to the overall project.
2. It allows more than one member to concurrently act in the same role, thus allowing students to share and exchange experiences and act as peer-mentors.

Each student enters a project as an analyzer and, after the analysis phase is completed, all students' roles are extended to designers. The leader of the group in the design phase can be the same student as in the analysis phase, or the leader role can be assigned to another student at the beginning of the design phase. Also, in the same phase, the leader can be changed from time to time according to the supervisor requirements and the group decision.

CVAG differs from traditional hierarchical models, where the supervisor is the leader of the group and s/he has the role to manage and control the group at all the time. In CVAG, the supervisor focuses on mentoring the group progress, and evaluating the work and the individual contributions. CVAG is designed to be used inside a programming class, therefore, the supervisor is typically the instructor for the class, and the person that prepares the programming task requirements. The group leader is one of the group members

Role	ARG	CVAG
Leader	No	Yes
Analyzer	No	Yes
Designer	No	Yes
Author	No	Yes
Time keeper	No	Yes
Explainer	Yes	Yes
Recorder	Yes	No
Gate-keeper	Yes	No
Direction giver	Yes	No
Clarifier/paraphraser	Yes	Yes(*)
Summarizer	Yes	No
Accuracy coach	Yes	Yes(**)
Understanding checker	Yes	No
Elaborator	Yes	No
Perspective-taking roles	Yes	No
Idea criticizer	Yes	No
Justification asker	Yes	No
Differentiator	Yes	No
Integrator	Yes	Yes
Extender	Yes	No
Prober	Yes	No

(\*) This role can be useful to be used in case of students need more clarification about the project.

(\*\*) This role known in CVAG as Navigator.

Table 3: The transferred roles from ARG to CVAG in addition to the new added roles to CVAG

and, as we mentioned before, the group members can decide who is the leader and how the role can be changed from member to member over the time.

CVAG supports the supervisor with all features necessary to facilitate his/her work to mentor and evaluate the work progress. S/He can trace the work progress and send comments to the group.

### 3.6 Communication Features (Video, Audio and Chat)

It is very important to ensure that the group members maintain open communication at any point in time during the different phases of the project. Therefore, it is important to provide communication channels between users, especially in those situations where users have a virtual presence (e.g., an avatar) in the collaborative virtual environment. The different types of communication channels can be used in group meetings, orientations, or as an any-time communication throughout the development of the project. Moreover, the group needs to communicate to share knowledge, make a conversation, make a decision, etc. Text chatting and audio.video (video-conference) are two types of communication channels that are supported by CVAG.



Role	Definition
Author (driver)	Creates the actual program by performing the required transactions, such as: adding and modifying classes and objects, creating methods, creating functions, defining variables/parameters, creating events, etc.
Leader	Assigns roles, changes roles, submits the deliverable to instructor, reviews the work progress, shares ideas about the members contribution, encourages members to finish on time.
Analyzer	Analyses the project requirements and create lists of objects, methods, functions, variables, events, etc.
Designer	Designs a number of scenarios, the time line activities and events of the program, designs use-cases.
Time keeper	Follows the time records for the work progress, notifies members of the required time for doing subtasks, notifies members of the deadline to finish the subtasks, and notifies members of the time to switch roles.
Explainer	Shares ideas and opinions.
Clarifier / paraphraser	Restates what other members have said to understand or clarify a message.
Accuracy coach (Navigator)	Reviews the created program by looking for errors, thinking about the overall structure of the code, finding necessary information and brainstorming with the group.
Integrator	Integrate members ideas and reasoning into a single position that everyone can agree on.

Table 4: CVAG roles' definition

- **Chat:** is the basic communication channel that CVAG provides to keep the group contact. Chat, i.e., the ability to send immediate text messages between team members, is a core feature in CVAG. Chat is a form of interaction that is immediate; a student can open a chat channel either to communicate with a specific other team member or with the entire team; the supervisor is also part of the communication process. CVAG allows the instructor to send a private message to a specific student in the group or to broadcast information to the entire team. This type of communication channel can be useful to send information to others with details (e.g., send correct syntax of a programming statement, properties' values, the correct object name, etc.), transfer knowledge to others, transfer experiences or skills to others, etc.
- **Audio\_video (video-conference):** video conferencing is an ideal communication media to enable group meetings; it is encouraged media for both small group and large group meetings. Students hang out in a video-conference, according to schedule times. Video conferencing is often not a

good practice for quick communications during the development process—as it can be a cause of distraction [30].

### 3.7 Orientation and Group Meetings

CVAG supports users (e.g., students) that are geographically dispersed; thus, it is critical for CVAG to provide opportunities for students to interact. We discussed in the previous sections the communication channels that CVAG provides to the users. These channels of communication are available at all times. Nevertheless, efficiency could be gained by ensuring that communication is introduced in a well-structured context, and realized according to a specific time schedule. In CVAG, three types of meetings are designed for users (students and teachers), to facilitate their work and support them with the required space to discuss, share, and transfer knowledge, experiences and skills. The three types of meetings differ in the time, purpose and/or communication channel, and they are discussed next.

**Orientation:** In the CVAG model, the group members are students who attend an introductory class to learn programming (e.g., an AP Computer Science Principles course). At the beginning of a programming course, students participate in an *orientation*, prepared to allow students to:

- Understand the philosophy and goals of CVAG,
- Understand the cooperative paradigm and learn about the requirements to learn programming in a collaborative setting,
- Become aware of teacher’s expectations, and
- Understand the resources and features that CVAG provides to support their collaborative efforts.

The orientation is mandatory and realized using the audio-video communication channels—this is fundamental to allow remote students to connect and meet for the first time.

The orientation is a structured event. It starts by requiring each student to introduce her/himself, possibly following an established script. This is followed by a presentation from the instructor, describing the project, goals, requirements and his/her expectations. The orientation provides a space for students to present what they expect from taking the course and what their programming background is.

**Small Group Meetings:** Small group meetings are expected to occur frequently throughout the development of the project. We will distinguish two types of small group meetings. The first type includes *regularly scheduled meetings*, typically occurring on a daily or bi-daily basis. A small group meeting can be held to discuss the work progress, work that has just been completed, following tasks, members’ roles, problems that have been encountered and possible solutions. Small group meetings may involve the entire team or a subgroup (established by the instructor). These meetings can make use of any communication channel—though video conferencing might be a preferred

channel to ensure a more direct and complete interaction. CVAG recommends these meetings to be scripted to ensure that all students have the opportunity to communicate and that the goals of the meeting are properly met.

The second type of small group meeting includes impromptu meetings, typically including a small subset of team members, and called on-the-fly to address an immediate need (e.g., a difficult bug). These meetings are typically unscripted, brief, and conducted in close temporal proximity with the task prompting the need for communication. Text messages and text chat are preferred communication channels, as they are less distracting and enable communication to occur while the students are still engaged in project activities (e.g., while they develop code) [30].

**Large Group Meetings:** Large group meetings in CVAG include all members of the team and they correspond to major milestones of the project. During a large meeting, the group shares announcements related to overall team achievements, such as published papers, awards, completion of major components, etc. The collaborative virtual model, in our case, will also include a large group meeting after each major learning milestone included in the project (e.g., submission of a part of the project, performance of an examination). Large group meetings are scheduled, scripted, and require the use of video-conferencing.

### 3.8 Project Management

#### *3.8.1 Resource Management*

In ARG, resource management means making suitable resources available to the right user. The available resources in ARG include items like lab time, office space, essential books, tutorials, etc. which are required to support the group's research project. Similarly, CVAG is designed to provide the proper resources to each student. Differently from ARG, CVAG customizes the resources provided based on the specific role(s) of the student. For example, a student serving as a recorder can open a writing board to collect the group's decisions during the group work or in a meeting. Furthermore, CVAG's resources are designed to reflect the fact that the team operates in a virtual space. The provided resources are automatically managed by the system according to the user's role(s). Since the roles are dynamic, the provided features will also change dynamically, reflecting the changes in students' roles. A change in role is not a trivial task—as it requires transferring complete control of features from one team member to another, making the use and appearance of the feature as seamless as possible. For example, when a recorder writes on the virtual white board the group's decisions, the board is visible to the entire group (in read-only modality). When the role is assigned to another member, the new member should be given write authority to the virtual white board, and thus the ability to continue work on the same decisions taken earlier by the group, as captured by the previous recorder.

### 3.8.2 Consistency

In a group of students that work together as members in a collaborative team, the issue of consistency arises and needs to be addressed. We refer to consistency as the guarantee that the created program seen by the team members are actually *identical* and *non-contradictory*. Identical views ensure that all team members are up-to-date with all changes being made (regardless of who made them). Lack of contradictions implies that all team members should be somehow prevented from making concurrent and conflicting changes to the same entity of the program. The consistency problem arises from the fact that CVAG allows concurrent driver roles, thus enabling different students to actually create code belonging to the same project at the same time.

In general, any implementation of CVAG should apply a specific algorithm to meet the consistency requirements. In section 5, we present *AliCe-ViLlagE* as an example of an implementation of CVAG. The implemented algorithm uses a relatively straightforward mutual exclusion technique to prevent a conflict on specific parts being modified. Each Alice program contains a number of classes, objects, methods, and functions. *AliCe-ViLlagE* achieves consistency by placing mutual exclusion locks on each one of these entities whenever they are accessed by a student for creation/modification. Concurrent attempts to modify the same unit of code will cause an arbitrary sequencing of accesses; access counters can be used to ensure the lack of starvation. This approach reduces to the minimum the risk of inconsistencies (see also Section 5).

### 3.9 People and Resources Awareness

Garcia et al. [13] define *awareness* in team work as an understanding of the activities of others, which provides a context of someone's own activities—making awareness core component of any collaborative environment. The distributed nature of the team in a CVAG setting makes the implementation of awareness even more critical and complex. In the design of CVAG, different types of features are provided to support awareness. Not only CVAG promotes understanding of the membership of a team, but also supports the understanding of the roles and capabilities owned by each team member at any point in time. CVAG provides the team with a feature that allows each member to view the list of members, including the role of each member. In this case, each member will know what s/he can do and what are the other members' capabilities and limitations. Furthermore, CVAG supports *Situational Awareness*, by allowing each student to understand their mutual "position" within the code, facilitating joint resolution of problems and reducing the risk of conflicts.

The group uses different types of communication channels to additionally create a level of *social awareness*. Students within the same group can communicate and interact throughout the project, facilitating the establishment of social relationships. While other virtual environments rely on avatars to provide a form of users' embodiment, CVAG enables situational awareness

through text based notifications describing the specifics of each user's transaction.

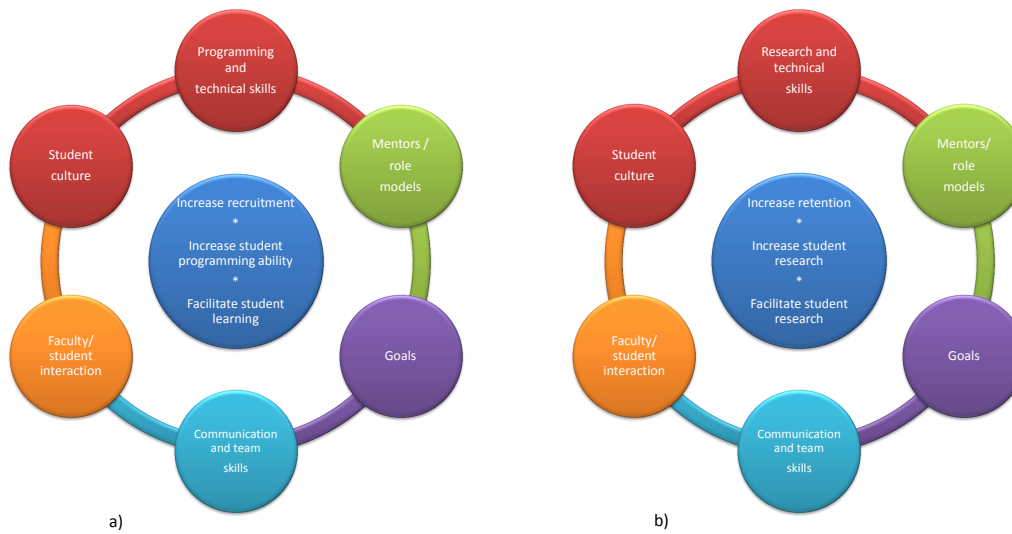


Fig. 3: The CVAG (a) vs. ARG (b) components

#### 4 CVAG vs. ARG

The CVAG model has been designed as an extension and adaptation of the Affinity Research Group (ARG) model. ARG provides the opportunity to students to learn, use, and integrate their knowledge and skills while working on a joint research project. In ARG, students work collaboratively and the model provides them with the structure necessary to gain knowledge and skills while achieving a collective project goal. The Collaborative Virtual Affinity Group model (CVAG) provides students with:

- The opportunity to learn programming in a collaborative virtual environment, working as part of a distributed team,
- The opportunity to gain the required experiences and skills to work in an affinity group,
- A suitable environment for middle and high school students to learn programming,

In some ways, CVAG is, at the same time, both a generalization as well as a restriction of ARG. It serves as a restriction of ARG as it focuses exclusively on the creation and support of teams of students engaged in learning fundamental concepts of programming and computational thinking—while the original ARG model can be applied to a wide range of learning experiences.

On the other hand, CVAG provides an extension of ARG by relaxing the time and space restrictions of ARG. Figure 3 shows the main components of ARG and how they have been modified to meet the goals of CVAG. The core goals of ARG, summarized in the middle circle in Figure 3b), are: increased retention, increased students research, and facilitated student research. The main goals of CVAG are, instead, shifted from research to learning (computer programming).

In section 3.3, we reviewed the different ARG components and discussed how they are mapped to the CVAG model. The core purpose and the other five components of collaborative environments have been adapted for CVAG, in order to make them suitable to be used in virtual environments. These types of changes require the model to be designed to handle geographically distributed teams of students. Moreover, CVAG defines a number of communication channels for students to facilitate interaction regardless of geographical location. On the contrary, these features are not necessary for ARG. All of the additional features which can be found in the design of CVAG but not in the design of ARG are related to the virtual and distributed nature of the former. Therefore, consistency, persistence, low-level application communication, user communication, etc. are features that specifically belong to the realm of CVEs, and are thus absent in ARG.

The other important difference between ARG and CVAG is the target audience. The typical audience of ARG is composed of graduate and undergraduate students engaged in research projects. The main target audience of CVAG is composed of teachers and students at the middle and high school levels, engaged in homework and class projects while learning introductory programming.

## 5 A Concrete Implementation of CVAG

The design of the CVAG model discussed in the previous sections has been validated in a concrete implementation—built on the block-based interactive learning environment called *Alice* [8].

Alice was originally developed as an interactive programming environment, freely available, and designed to teach students the fundamental principles of programming—including relatively advanced features, like object oriented programming. Alice is extensively used at the middle and high school levels. The design and implementation of new features and functionalities in Alice facilitate concurrent programming of 3D worlds by a *distributed group of programmers*, following the principles of CVAG. We refer to the resulting environment as AliCe-ViLlagE. Thus, *AliCe-ViLlagE* is an application to collaborate and to learn programming within a collaborative virtual environment. By building this environment, we combine the benefits of using a well-established educational platform like Alice in teaching programming and the benefits from using collaborative models in programming and learning, e.g., increased technical experiences and skills exchange, sharing of information, better program



Fig. 4: The group member information. The figure show that the group has three members (as the number at the top right side of the window) and the user show the information of the third member

quality with fewer bugs, and enhanced student confidence. The first prototype of *AliCe-ViLlagE* has been presented in [1] and focuses on generalizing Alice to support (virtual) pair programming. The second version of *AliCe-ViLlagE* implements CVAG. The following is a summary of this second version of *AliCe-ViLlagE*.

### 5.1 The User Interface of *AliCe-ViLlagE*

The graphical user interface (GUI) of Alice has been extended in *AliCe-ViLlagE*. We explicitly emphasized the importance of making the novel features of *AliCe-ViLlagE* as non-intrusive as possible, to reduce the learning curve of *AliCe-ViLlagE* for students who are already familiar with Alice, and to avoid overwhelming inexperienced students with a complex interface. In particular, all of the code development tasks of Alice are available unchanged in *AliCe-ViLlagE*, and they are presented to the users with exactly the same visual interface—e.g., add an object to the world by selecting the “*add object*” button and choosing the object from gallery, drag and drop statements into the methods, etc.

The new components in the *AliCe-ViLlagE* interface are related to the added functionalities of *AliCe-ViLlagE* as a virtual collaborative environment. When the user starts the application, *AliCe-ViLlagE* will prompt the user with a login dialog, requesting a user-name and a password. These two pieces of information have a dual role:

- They provide security to the users (e.g., protecting the course-work that a student is developing from unintended accesses);
- The user name allows the identification of the user, necessary to place the user in the appropriate team and to assign him/her the selected role(s).

Information about users, teams and roles are maintained in an internal database within *AliCe-ViLlagE* on the server side.

In the main window of *AliCe-ViLlagE*, the user is presented with the same interface as Alice, with the three new components. The first component is a

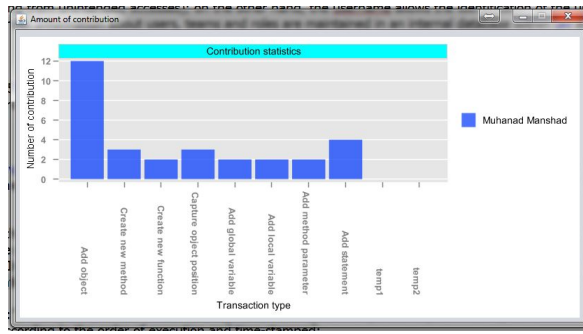


Fig. 5: The contribution of a user in the team

Name	Action type	Action	Time
essa	1	!#gallery/Animals/Boar.a2c	Sun Oct 04 15:24:51 MDT 2015
tanash	1	!#gallery/Animals/Bird1.a2c	Sun Oct 04 15:25:03 MDT 2015
tanash	1	!#gallery/Animals/Bird1.a2c	Sun Oct 04 15:25:38 MDT 2015
tanash	1	!#gallery/Animals/Bunny.a2c	Sun Oct 04 15:26:13 MDT 2015
essa	1	!#gallery/Animals/Bluebird.a2c	Sun Oct 04 15:26:43 MDT 2015
essa	1	!#gallery/Animals/Bluebird.a2c	Sun Oct 04 15:26:55 MDT 2015
tanash	1	!#gallery/Farm/FarmHouse.a2c	Sun Oct 04 15:27:01 MDT 2015
tanash	1	!#gallery/Farm/WeatherVane.a2c	Sun Oct 04 15:27:19 MDT 2015
essa	1	!#gallery/Farm/Scarecrow.a2c	Sun Oct 04 15:27:42 MDT 2015
essa	1	!#gallery/Farm/Scarecrow.a2c	Sun Oct 04 15:27:45 MDT 2015
essa	1	!#gallery/People/AliceLiddell.a2c	Sun Oct 04 15:28:21 MDT 2015
tanash	1	!#gallery/People/RandomGuy1.a2c	Sun Oct 04 15:28:26 MDT 2015
essa	1	!#gallery/People/RandomGuy2.a2c	Sun Oct 04 15:28:59 MDT 2015
tanash	1	!#gallery/People/BikeKid1.a2c	Sun Oct 04 15:29:03 MDT 2015
essa	1	!#gallery/People/RandomGuy2.a2c	Sun Oct 04 15:29:05 MDT 2015
essa	1	!#gallery/Park/ParkBench.a2c	Sun Oct 04 15:30:17 MDT 2015
essa	2	2#edu.cmu.cs.stage3.alice.core.response...	Sun Oct 04 15:33:26 MDT 2015
tanash	2	2#edu.cmu.cs.stage3.alice.core.response...	Sun Oct 04 15:33:36 MDT 2015
essa	2	2#edu.cmu.cs.stage3.alice.core.response...	Sun Oct 04 15:34:11 MDT 2015

Fig. 6: The transaction log show all transaction for all user

new menu item in the menu bar, called *Collaboration*. The second component is a new button labeled *Chat*. The third component is a text message field located in the tool bar.

The Collaboration item is a menu with four options:

1. “*Chat:*” this option establishes a chat window with the other team members and the user in the window can establish a video conference (synchronized audio and video) with other team members; the student can also request the chat using the shortcut button on the tool bar;
2. “*Partner Information:*” this option allows the user to retrieve basic information about the other team members (Figure 4), including his/her identity, his/her current role(s), and a list of the most recently performed operations by the partner. The “Show contribution” button displays a chart of the transactions performed by the partner, organized by type of transaction (Figure 5);
3. “*Transaction Log:*” this option provides access to a log file containing all the operations performed by all team members, sorted according to the



order of execution and time-stamped (Figure 6). The user can also request a chart containing the statics about all the transactions performed by the entire team (Figure 1);

4. “*User Profile:*” this option allows the user to review his/her own profile and manage the information in it (e.g., modify password); the user profile allows the user to also change his/her role, if the supervisor has granted permission to do so.

## 5.2 Users Information

*AliCe-ViLlagE* keeps the required information in an XML database. The database has the basic information about each programmer: user name, password, roles, etc. and the basic information about the project that each team is currently working on. Users information is saved on the server side. When the user enters his/her information to login (user name and password), the *AliCe-ViLlagE* client sends a message to the server; if the server finds the user, it will return an acknowledgment containing the complete user record (e.g., the user role), otherwise, the user receives an error message. Please note that the users are created by the instructor, in order to provide a control on the format of created teams.

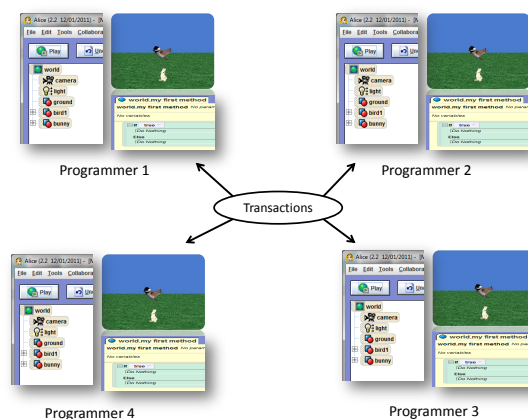


Fig. 7: The transaction broadcast to all members

## 5.3 Application-level Communication Mechanisms

*AliCe-ViLlagE* is a collaborative virtual environment that provides synchronous view of a shared 3-D world on different workstations (users' sides), connected

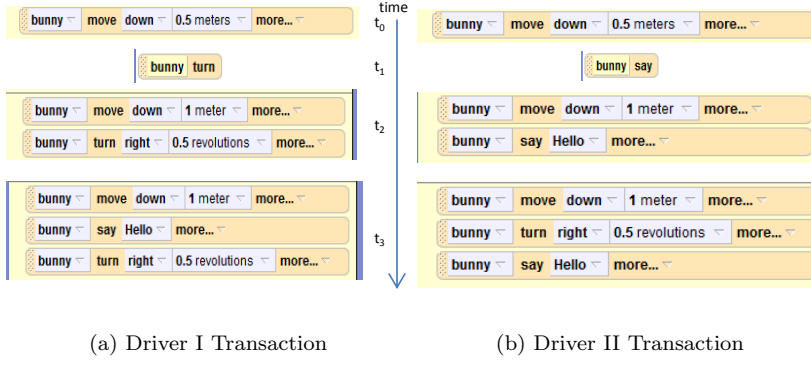


Fig. 8: The transaction executed at two drivers sides according to the time. At time  $t_0$ , the two drivers have the same state. At time  $t_1$ , both driver drag a statement to add it to the method, after that the statement added as in time  $t_2$ , then a transaction message sent to add the statement on the partner side, after receive the message which say to insert the statement at index 1 (after the first statement), the final state on both side as in time  $t_3$

through the Internet. In order to ensure synchronous behavior as well as to provide all the communication channels described earlier (e.g., notifications of changes, audio/video communications), *AliCe-ViLlagE* needs a communication layer that supports the exchange of events among the remote partners. The transfer of events between users is realized through *RabbitMQ* [28]. RabbitMQ is an open source message broker software, that provides a reliable method to send and receive messages. The Advanced Message Queuing Protocol (AMQP) implemented in RabbitMQ is a suitable protocol for *AliCe-ViLlagE*. Two team members' sessions are connected by an exchange message queue; each team member will broadcast a message to other team members. Figure 7 show four members in a group and how they are connected. The interface for the four members are identical and all of them see the same components—i.e., world scene, project browser, methods, etc.

#### 5.4 Consistency Implementation

Let us further elaborate on the two aspects of consistency. Consistency can be lost as result of two potential situations—resulting in two or more team members in the group seeing different versions of the Alice 3D world:

1. The first situation occurs when a transaction performed by one team member is not received by other team members (and, thus, not reflected in the 3D worlds seen by some members of the team).
2. The second situation derives from conflicting changes. Two or more team members (e.g., all acting as drivers) may apply conflicting modifications to the same object of the world; for example, two students may both drag and

drop a distinct statement in the same method. The order of statements in the method is important, and there is a danger that such order will differ in the two 3D worlds. For example, Figure 8a and Figure 8b show the transactions executed by both drivers on each side, resulting in inconsistent methods. Similar problems may occur when two students modify the same property of an entity at the same time—depending on the speed of communication, the 3D worlds may result in different values of such property (or, in a less “threatening” case, one of the changes may be lost).

The first situation may occur for various reasons, ranging from shutdown of one of the machines to transient communication problems. The solution for this problem relies on the use of acknowledgment messages. Several well-established schemes have been proposed in the distributed computing literature to address unreliable communication, through the use of delays and acknowledgment messages. The current implementation of *AliCe-ViLlagE* makes use of a relatively simple approach: after each transaction is sent to all machines, an acknowledgment message should be sent back. If no acknowledgment message is received within a given time window, a flag will be set in the log file to show that the transaction has not been properly executed and all team members are alerted of the problem. In this case, the student may have to wait until the remote 3D world is properly updated.

The second situation can be resolved using lock messages, generated by the drivers before performing a transaction and associated to the entity which is the subject of the transaction (e.g., driver 1 may generate a lock message associated to method1 before performing a drag and drop of a statement in method1). The actual transaction will be performed only after locking the local entity and receiving an acknowledgment message indicating that the entity has been successfully locked on all remote machines. The locking may fail, e.g., if the entity is already locked by the other team member; in such a case, the current entity will be released, the transaction will not occur and the driver will be notified. If the lock is successful, then the transaction will be executed on the current entity and a message sent to the remote machines to request the proper update of the entity. The receipt of the transaction will also correspond to the unlocking of the remote entity. If drivers fail to complete a transaction because they noticed that two or more of the other students are working on the same entity, then they can communicate to coordinate the work.

## 6 Conclusion and Future Work

In this paper, we presented a generalization and adaptation of the Affinity Research Group (ARG) model, which enables its application and use to support learning introductory programming in a collaborative virtual environment. The paper discussed the different components of the resulting model, called CVAG, comparing and contrasting it with ARG and with other fundamental principles underlying the design of collaborative virtual environments. The

resulting model has been implemented in a concrete learning environment, *AliCe-ViLlagE*.

The current research directions are aimed at completing the development of a robust version of *AliCe-ViLlagE* that can be disseminated to the public; we are also exploring the formal assessment of *AliCe-ViLlagE* in both a classroom setting (e.g., in a course adopting the College Board Computer Science Principles curriculum) as well as in an after-school program for middle school students. We are also exploring how to lift the principles of CVAG to make them applicable to other introductory programming learning environments, such as Scratch [24] and AppInventor [4].

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